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16. Abstract The application of the American Association of State Highway and Transportation Officials' (AASHTO) Highway Safety Manual (HSM) to Louisiana roads is a key component to the Louisiana Department of Transportation and Development's (DOTD) plan to improve safety on state highways and reach the goal of <i>Destination Zero Deaths</i> . The goal of this project was to develop Louisiana state-specific HSM calibration factors for eight facility types. During the completion of the project, the data-intensive computational process undertaken to compute the calibration factors revealed numerous issues associated with the input data required by the HSM. These included, most notably, coding errors and missing required data elements in the Louisiana roadway and crash databases. Some of the resulting factors were unexpected, in particular, those for urban three lane and urban five lane highways which were lower than anticipated. These factors may warrant further analysis beyond which was required for this project, including detailed assessments of each crash report to ensure data accuracy. The remaining calibration factors for rural two lane, rural multilane undivided and divided, urban/suburban two lane, and urban/suburban four lane divided and undivided highways, ranged from a low of 0.62 for rural multilane undivided highways to a high of 2.54 for urban/suburban four lane divided highways. It is expected that with an understanding of the conditions under which these factors were developed, that they will be acceptable for use by analysts seeking to conduct highway safety analyses for roads in Louisiana.					
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Calibration of the Louisiana Highway Safety Manual

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ABSTRACT

The application of the American Association of State Highway and Transportation Officials' (AASHTO) Highway Safety Manual (HSM) to Louisiana roads is a key component to the Louisiana Department of Transportation and Development's (DOTD) plan to improve safety on state highways and reach the goal of *Destination Zero Deaths*. Part C of the HSM includes Safety Performance Functions and Crash Modification Factors that, when used in conjunction with "local" calibration factors, can be used to predict the safety along road segments. The goal of this project was to develop Louisiana state-specific HSM calibration factors for eight facility types. During the completion of the project, the data-intensive computational process undertaken to compute the calibration factors revealed numerous issues associated with the input data required by the HSM. These included, most notably, coding errors and missing required data elements in the Louisiana roadway and crash databases. Some of the resulting factors were unexpected, in particular, those for urban three lane and urban five lane highways which were lower than anticipated. These factors may warrant further analysis beyond which was required for this project, including detailed assessments of each crash report to insure data accuracy. The remaining calibration factors for rural two lane, rural multilane undivided and divided, urban/suburban two lane, and urban/suburban four lane divided and undivided highways, ranged from a low of 0.62 for rural multilane undivided highways to a high of 2.54 for urban/suburban four lane divided highways. It is expected that with an understanding of the conditions under which these factors were developed, that they will be acceptable for use by analysts seeking to conduct highway safety analyses for roads in Louisiana.

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IMPLEMENTATION STATEMENT

The eight calibration factors developed in this project were computed for application to Louisiana state highways. It is anticipated that these calibration factors could be used statewide by analysts seeking to apply Part C of the HSM for projects in Louisiana. Because these factors were developed using a set of data that did not include all elements and characteristics suggested by the HSM, users should recognize which data were included in the computational process, what assumptions were made as it was carried out, and understand how these data and assumptions and data limitations may impact the outcomes of safety analyses conducted in Louisiana.

It is also suggested that, prior to using these factors, an additional step can be taken to ensure computational reliability. Users of these factors may wish to review traffic crash reports individually, to determine whether crashes were properly coded by the responding police agency as “intersection-related” or “segment-related.” The research here shows that specific crash characteristics greatly impact the predictive capability of the factors. In fact, it is recommended that a detailed crash report–specific reanalysis of this project could be undertaken comprehensively by DOTD prior to releasing the calibration factors for statewide general use.

In addition to completing this project with the 2009-2011 traffic crash and roadway design data, supplemental analyses outside of the scope of this study are underway to apply 2012 data to assess the consistency and applicability of the calibration factors to more recent crash experience. Once available, these results can be shared with DOTD staff.

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INTRODUCTION

The state of Louisiana consistently ranks near the bottom in national statistics regarding highway safety, particularly traffic crash related fatalities. To counter these conditions, the Louisiana Department of Transportation and Development (DOTD) has initiated several safety-related campaigns over the recent decade; among these is the Louisiana Strategic Highway Safety Plan (SHSP). The goal of this program is to reach “Destination Zero Deaths” on Louisiana roadways by reducing the human and economic toll on Louisiana’s surface transportation system through various collaborative efforts and an integrated 4E approach (Education/Enforcement, Engineering and Operations, Emergency Services, Everyone Else!).

In conjunction with these Louisiana efforts, the past several decades have seen many new highway safety related innovations on a national level. One of the most promising recent developments has been the 2010 publication of the Highway Safety Manual (HSM) by the American Association of State Highway and Transportation Officials (AASHTO). The HSM includes analytical tools and techniques for quantifying the safety effects of planning, design alternatives and configurations, and operations and maintenance decisions. However, since the HSM has been developed based on national trends and statistics, it must be calibrated for local use. This calibration allows it to better represent local conditions. The HSM provides guidance on the calibration procedure in Volume 2 Appendix A (V2, AA). The primary goal of this project will be to calibrate the HSM according to the procedure in V2, AA for a variety of road types so that it can be utilized with greater effectiveness in Louisiana.

In the following sections of this report, the objectives of this study are described then the scope of this work and its areas of application in Louisiana are summarized. This is followed by a review of literature to provide background on the HSM, including its development, content, and prior applications that are relevant to this work. Later, details of the data and methods used to compute the Louisiana-specific HSM calibration factors for the various road types are described accompanied by the quantitative results of these efforts. Finally, important conclusions that were drawn from this work are discussed as well as suggestions for the application of this new knowledge in Louisiana are offered.

Literature Review

To inform this work and to assess its methods and outcomes relative to the current state of HSM-application practice, a review of literature relevant to this research was conducted. In addition to a summarization of the HSM predictive method, the review also focused on two

significant issues that have arisen when other states have used the HSM predictive method: site selection and method of calibration.

The HSM recommends randomly selecting 30 to 50 roadway segments upon which at least 100 crashes occur annually for each facility type. The HSM defines a roadway segment as “a section of continuous traveled way that provides two-way operation of traffic, that is not interrupted by an intersection, and consists of homogeneous geometric and traffic control features” [1]. In prior analyses, this task has proven to be quite complicated due to the data limitations and seemingly arbitrary number of target sites. Also, because the HSM’s Part C SPFs were developed with crash data from around the country, they must be calibrated for local application in one of two ways – applying a calibration factor or developing local SPFs.

This literature review summarizes the strategies, difficulties, and outcomes of the site selection process and calibration efforts in Utah, Florida, Kansas, North Carolina, Oregon, Alabama, and Virginia with the goal of determining the most efficient site selection process and evaluating which calibration method may provide more reliable crash prediction results for application in Louisiana.

HSM Predictive Method

In 2010, the first edition of the Highway Safety Manual (HSM) was published by the American Association of State Highway and Transportation Officials (AASHTO). This manual was the first of its kind and represented a significant advancement in the highway safety field. The HSM provides transportation professionals with quantitative methods to aid in the safety decision-making process. One of the key components of the HSM is a computational procedure to forecast crash frequency based on various traffic and roadway characteristics. It can be used to predict future crash frequency and severity of a site or to identify high crash sites that are in need of safety improvements.

The predictive method is an 18-step process used to predict the safety of a roadway segment or intersection in terms of its expected crash frequency and severity based on its geometric and roadway characteristics and traffic volumes. This method can be implemented to “reduce the vulnerability of historical crash-based methods to random variations of crash data” [1].

To apply the predictive method, safety performance functions (SPFs) found in Part C of the HSM are used to calculate the predicted average crash frequency of a site under base conditions. Each facility type – rural two-lane, rural multilane, and urban and suburban

arterials – has its own set of SPFs specific to the segment type. Next, to account for local variations from the base conditions, appropriate crash modification factors (CMFs) are multiplied by the SPFs. Examples of CMFs include lane and shoulder width adjustments, presence of lighting and rumble strips, and the presence of automated speed enforcement.

Finally, the Part C SPFs were developed using national data, which can “vary substantially from one jurisdiction to another for a variety of reasons including climate, driver populations, animal populations, crash reporting thresholds, and crash reporting system procedures [1]. Therefore, for the Part C SPFs to provide reliable results for a jurisdiction, they must be calibrated for local application. This can be accomplished through the use of a calibration factor or the development of jurisdiction-specific SPFs.

The calibration factor (C) is the ratio of the total number of observed crashes, determined by historical crash data, to the total predicted number of crashes, which is estimated using the predictive method. When the calibration factor is used, the predictive method takes the form of the following equation, which can be found in the HSM, where $N_{\text{predicted}}$ is the predicted average crash frequency:

$$N_{\text{predicted}} = \text{SPF} * (\text{CMF}_1 * \text{CMF}_2 * \dots * \text{CMF}_n) * C \quad (1)$$

An alternative approach to making crash prediction results applicable for a particular jurisdiction involves developing jurisdiction-specific SPFs using statistically valid methods such as negative binomial regression. The HSM suggests that when it is feasible, local SPFs should be developed; this allows each state to determine its preferred method of calibration.

One of the most significant challenges of applying the predictive method is dividing the roadway into homogeneous segments and randomly selecting a sample that satisfies the HSM recommendations. The HSM recommends using a minimum segment length of 0.10 miles and randomly selecting at least 30-50 segments on which at least 100 crashes occur annually for each facility type to ensure a representative sample. Once the segments are selected, the next challenge that arises is collecting the extensive amount of data elements, which can be found on Table A-2 in Appendix A of the HSM. Some of the required data elements include segment length, AADT, lengths and radii of horizontal curves, lane and shoulder width, presence of lighting and on-street parking, and the driveway density.

Segment Selection Practices

Utah

The Utah Department of Transportation (UDOT), together with Brigham Young University, utilized the HSM's predictive method to calibrate the SPF for rural two-lane, two-way roadway segments throughout the state of Utah. The site selection process involved randomly selecting segments based on geometry and roadway characteristics and then removing segments with unrepresentative AADT data and those which had recently undergone improvements [2].

This calibration did not include local roads due to data limitations, and only tangent sections of roadway were included. Segments within 250 feet or 0.05 miles of a horizontal curve were eliminated from the dataset to simplify the calibration procedure. This limits the applicability of the calibration factor to tangent roadway segments along state and federal highways.

Once all of the data had been collected, the segments that were not representative of rural two-lane, two-way roadways in Utah were eliminated. These segments include those with AADT values greater than 10,000 veh/day and those with speed limits less than 50 mph. Although this affects the randomness of the dataset, they justify this by stating that those segments' "extreme characteristics undermine the predicting capability of the SPFs" [2]. Ultimately, 157 segments were selected for inclusion in the calibration set, compared to the 30-50 site minimum recommended by the HSM [2].

Kansas

The Kansas Department of Transportation (KDOT) commissioned this study to validate the accuracy of the SPF for rural two-lane roads in Kansas to decide whether or not to implement the HSM predictive methodology in their project development process [3].

The segments for calibration were selected using a random segment generator previously developed by the University of Kansas for another research project. Fifty random ten-mile long sections were generated, but nine were removed because they did not meet the HSM's definition of two-lane rural segments. From these 41 segments, 19 were selected for calibration with a minimum of three segments from each of the six KDOT geographic districts to ensure a good geographic representation [3].

The report states that defining the term “rural” was one of the biggest challenges of the study. The HSM’s definition of “rural” is any segment outside of an urban area with a population less than 5,000. Some of the segments qualified as “rural” under these conditions; however, the other roadway features including on-street parking, sidewalks, and downtown-style development, make these segments difficult to model using the rural two-lane SPF. Because of this, all segments in this study were modified to exclude segments going through cities of any population [3].

Oregon

The Oregon project team implemented the HSM’s predictive method to calibrate the SPFs for Oregon’s rural two-way roads, rural multilane highways, and urban and suburban arterials. Site selection was limited to state highway system segments due to data limitations of local roads. This limits the future use of the calibration factor to state highway segments. Only 19 rural multilane divided highway segments were found using the Oregon Department of Transportation (ODOT) database; therefore, each segment was used in the calibration. Because most urban and suburban crashes occur at intersections and not along roadway segments, a large number of segments were required to meet the 100 crash threshold. The project team selected urban and suburban sites until the threshold was reached [4].

One issue the project team noted about the HSM’s methodology is the arbitrary target number of sites and crashes. This number does not reflect the differences in crash frequency typically found when comparing facility types. The Oregon project team determined an appropriate number of sites based on facility type and historic crash data. 75 rural two-lane, two-way segments, 50 rural four-lane divided segments, 19 rural four-lane undivided segments, 491 urban two-lane undivided segments, 205 urban three-lane segments, 375 urban four-lane undivided segments, 86 urban four-lane divided segments, and 323 urban five-lane segments were ultimately selected for calibration [4]. From this report, it is evident that the “one size fits all” approach is not appropriate for different facility types’ calibration dataset sizes.

Florida

The University of Florida Transportation Research Center utilized the HSM’s predictive method to calibrate SPFs to reflect Florida roadway conditions for rural two-lane roads, rural multilane highways, and urban and suburban arterials [5]. The site selection process is detailed below.

Florida Department of Transportation's (FDOT) Roadway Characteristics Inventory (RCI) contains data for all FDOT-maintained roads. All segments labeled "Active on SHS" (state highway system) were selected to ensure adequate crash and geometric data for calibration. This limits the applicability of the calibration factors to segments that are part of the state highway system. Once the FDOT-maintained roads had been selected, a Python Script was written to automatically divide them into homogeneous roadway segments with a minimum length of 0.10 miles for rural segments and 0.04 miles for urban segments. This segmenting procedure created thousands of sites for calibration – about 4,800 for rural two-lane roads, 1,400 for rural multilane highways, and 17,000 urban and suburban segments [5].

Any segments that included intersections or curves were removed from the sample, thus simplifying the calibration process but also limiting the applicability of the calibration factors. This Florida study shows that by using a Python Script, the HSM's minimum site requirements for calibration can be far exceeded [5].

Calibration Methods

North Carolina

The University of North Carolina Highway Safety Research Center set out to develop local SPFs to aid the North Carolina Department of Transportation (NCDOT) in their decision-making process. They began by first calibrating six of the eight segment SPFs – rural four-lane divided, urban two-lane undivided, urban three-lane, urban four-lane divided, urban four-lane undivided, and urban five-lane roadway segments [6]. Next, SPFs were developed with AADT as the only independent variable. These were developed for 16 roadway types including rural two-lane roads, rural multilane divided, rural multilane undivided, urban two-lane, urban multilane divided, urban multilane undivided, rural freeways with 4 or 6+ lanes both inside and outside the influence of interchanges, and urban freeways with 4, 6, or 8+ lanes both inside and outside the influence of interchanges. Because these SPFs are so basic, with only one independent variable, they are most useful for network screening, or identifying locations that would benefit the most from a safety improvement. More complex SPFs were developed for rural two-lane roads with AADT and additional site characteristics including shoulder width and type and terrain [6].

While this study found that North Carolina-specific SPFs would provide more reliable results than calibrating the HSM Part C SPFs, this was not possible for some facility types due to a lack of sufficient data. The sample sites and number of crashes required to develop

statistically valid SPFs are much higher than those needed for calibration. The research team suggested that when deciding which method to select, the future application of the SPF must be taken into consideration. If the purpose of the SPFs is to help prioritize locations for safety improvements, developing a simple SPF based on AADT alone would be sufficient. However, if the SPFs are to be used to predict crashes for a specific project, it would likely be more straightforward to calibrate the HSM SPFs due to the extensive statistical knowledge required to develop more reliable SPFs with more independent variables [6].

Florida

The University of Florida Transportation Research Center utilized the HSM's predictive method to calibrate SPFs to reflect Florida roadway conditions for rural two-lane roads, rural multilane highways, and urban and suburban arterials. The rural multilane undivided highway SPF was not calibrated due to an insufficient number of sites of this type. State-specific SPFs were also developed for rural two-lane roads and urban and suburban four-lane divided highways, and their accuracy was compared to that of the calibrated SPFs to determine the best method for predicting average crash frequency in Florida. It was expected that state-specific SPFs would produce more reliable results than calibrating the HSM Part C SPFs due to the flexibility allowed by developing an SPF, compared with the linear relationship between the HSM SPFs and actual crash frequency that a calibration factor assumes [5].

The calibration factors were determined using the procedure in the HSM, and then the calibrated and uncalibrated models were compared. The prediction errors – the difference in observed and predicted crashes – from the uncalibrated and calibrated models were calculated and showed that “the most substantial benefit of calibration across all facility types is in the variance and range of the predicted errors” [5]. Overall, statewide calibration factors reduced the number of segments with extreme under- or over-predictions.

Locally-derived SPFs were developed using negative binomial regression and the same data that was required by the calibration factor calculation. All of the available segments were used in the model development, with no attention paid to “base conditions”; therefore, CMFs would not need to be applied to these Florida-specific SPFs [5].

After the calibration factors and local SPFs were developed, the accuracy of each was compared to determine the best method for predicting crash frequency in Florida. To do this, the calibration factors and local SPFs were re-developed using 80 percent of the available data and then applied to the remaining 20 percent. Next, the difference in observed and

predicted crashes was calculated to estimate an error. Based on the calculated errors, crash prediction was not improved overall by using the Florida-specific SPFs. Further future analysis was recommended to determine if the reliability of the state-specific SPFs improved with time [5].

Utah

The UDOT research team utilized the HSM's predictive method to calibrate the SPF for rural two-lane, two-way roadway segments throughout the state of Utah. In addition to this calibration factor, state-specific SPFs were developed for rural two-lane segments using negative binomial and hierarchical Bayesian modeling techniques with the goal of determining the best method for predicting crashes along Utah rural two-lane highways [2].

The Utah-specific SPFs were developed using the same data that was used in calculating a calibration factor, with the addition of speed limit and combo-unit truck percentage, which were expected to affect the predicted crash frequency. The statistical software SAS was used to develop four negative binomial models, and the statistical software R was used to develop one hierarchical Bayesian model. The negative binomial model with transformed AADT at a 95 percent confidence level produced the most reliable results and was therefore recommended for incorporation into UDOT's safety analyses. The Hierarchical Bayesian model would be most useful for predicting "hot spots" – locations with unusually high predicted average crash frequency [2].

The calibration factor was calculated using the method described in Appendix A of Part C of the HSM and resulted in a calibration factor of 1.16. To predict crashes using the HSM Part C SPFs with this statewide calibration factor, twelve CMFs would need to be applied. This effort was far more complex than using the state-specific SPF, which required four data elements – AADT, segment length, combo-unit truck percentage, and speed limit. While the calibrated HSM model predicted crashes more accurately than the state-specific SPF, it did not provide a substantial enough benefit to make it worth the additional time and effort [2].

While the report did not quantify the differences in the predicting capability of each method, both techniques—applying a calibration factor and developing state-specific SPFs—were deemed suitable for predicting crashes along Utah's rural two-lane segments. Because the newly-developed negative binomial model required fewer data elements than the HSM SPF, this was recommended for statewide use [2].

Kansas

The Kansas Department of Transportation study consisted of developing a statewide calibration factor to be applied to the HSM rural two-lane, two-way roadway SPF and developing new calibration methods, with the goal of determining the ideal calibration method for the state of Kansas [3].

Similarly to Louisiana, Kansas highways have a relatively uniform nature; therefore, a single statewide calibration factor was estimated. A statewide calibration factor of 1.48 was estimated with a standard deviation of 0.68. This relatively high value (nearly half of the calibration factor) concerned the research team who then sought to determine a more reliable method for crash prediction [3].

While conducting the calibration, the research team discovered a major difference between the HSM default crash distribution and the observed crash distribution along Kansas rural two-lane highways. 58.9 percent of the reported crashes were animal collisions, compared to 12.1 percent listed in the default HSM distribution. Because of this significant difference, the research team developed a method to account for animal crashes in their crash predictions. The most reliable method involved using the animal crash rate to calculate a variable calibration factor for a specific section of roadway [3].

While the unique calibration procedure developed by this study provided more accurate results for Kansas highways than the standard calibration factor derived using HSM procedures, neither method produced results that accounted for the various observed crash rates on Kansas two-lane rural roads. Because the calibration procedure did not result in a level of crash prediction accuracy that satisfied KDOT, the recommended next step would be to derive jurisdiction-specific SPFs [5].

Alabama

The University of Alabama completed a study for the Alabama Department of Transportation (ALDOT) comparing crash prediction methods for rural two-lane roads and four-lane divided segments to determine the best method for statewide implementation. Calibration factors were estimated for application with the HSM Part C SPFs using two methods – the one described in the HSM and also a new approach that uses negative binomial regression [7].

Four state-specific SPFs were also developed using Poisson-Gamma regression. A validation dataset, consisting of segments not used for the initial calibration, was used to determine

whether one of the calibration factor methods or a state-specific SPF was more accurate at predicting crashes along Alabama highways. The mean absolute deviance, mean squared prediction error, mean prediction bias, log likelihood value, and the Akaike's information criterion were all used to evaluate the different calibration methods and determine which one should be recommended for implementation by ALDOT [7].

One issue with the HSM predictive method is the seemingly random selection for the number of target sites (30-50) and crashes (at least 100) occurring on these sites. Due to the varying exposure of each facility type, one single target number of sites seems overly simplistic and not practical. The researchers at GENEX discuss this further and compare various dataset sizes to further analyze this. The data requirements for calibration are extensive and frequently are a challenge to those applying the HSM predictive method. This report states that there is "not much research available to provide guidance to the States on how the "goodness" of the calibration factor relates to the size of the calibration dataset" [8].

For rural two-lane roads, 5991 segments were used for crash prediction, and 3000 segments were used in the validation dataset. These segments ranged in size from 0.01 miles to 0.68 miles long. For the four-lane divided segments, 4000 sites were selected for calibration, and 2000 segments were used in the validation dataset. These segments were anywhere from 0.01 to 6.59 miles in length [7].

Both methods of estimating calibration factors result in a factor greater than one, suggesting that the HSM underestimates crash frequency for the state of Alabama. Ultimately this study finds that one of the four state-specific SPFs provides the most accurate crash prediction results; however, the HSM-recommended calibration factor method provides satisfactory results and requires much less effort to carry out [7].

Virginia

The Virginia Transportation Research Council performed this study to determine the best method of predicting crashes along state-maintained, two-lane segments in Virginia to assist in the prioritization of highway safety improvements. The HSM SPFs were first used to predict crashes, and then local SPFs were developed for total crashes and fatal plus injury crashes using 70 percent of the available sites. The remaining 30 percent was used to evaluate the locally-derived SPFs, which were then compared to the accuracy of the default SPFs [9].

Overall, the state-specific SPFs developed for Virginia provided much more accurate crash prediction results than the default HSM SPFs. It is possible that by splitting rural two-lane and urban two-lane datasets into rural and urban primary and secondary, the default SPFs would have improved crash predicting capabilities. However, the use of state-specific SPFs is recommended for predicting safety along state routes [9].

Findings

The Highway Safety Manual's predictive method is a process used to estimate the crash frequency and severity of a roadway segment or intersection based on its roadway characteristics and traffic volumes. One of the most critical steps in the predictive method is the site selection process. One common issue with this process is the data limitations of non-state routes. State DOTs generally have the data required by the HSM for calibration for state routes only. This limits the calibration factors to state highway system routes. Another issue arises in segments with horizontal curves. The HSM requires two additional data elements for horizontal curves on rural two-lane roads – lengths of horizontal curves and tangents and radii of horizontal curves. Although this will increase the workload required for data collection if this information is not readily available on the state database, it should be included if possible, so as not to further limit the predicting capability of the SPF.

Another issue with the segment selection process is removing sites that have undergone recent geometric design and traffic control changes to avoid distorted crash data. The HSM does not specify how recent these improvements can be without affecting the data. This type of effort will need to be updated on a continuing basis into the future on all safety-related studies. Another concern arises when a state's database classifies a segment as rural, but the segment does not meet the HSM's definition of rural. Ultimately, classifying an area as urban, suburban, or rural is at the user's discretion [1]. This must be determined by careful verification of each of the segments.

The Florida study made use of a script to automate the segmentation procedure. Not only did this reduce the time and effort required by the site selection process, but it also allowed them to use thousands of sites in their calibration, far exceeding the HSM's minimum of 30 to 50 sites [5]. The site selection methodology of Utah, Florida, Kansas, and Oregon has provided a basis upon which the Louisiana calibration factors will be determined, as well as addressing some of the potential issues that may arise during the segment selection process [2,3,4,5].

The calibration effort (by others) is underway in Louisiana with the statewide calibration factors and state-specific SPFs scheduled for completion in late 2014. It is important to note that “even though the random nature of crashes results in a significant level of uncertainty in predicting crashes for any single project, this uncertainty can be reduced in part by producing more reliable calibration factors” [8]. This is the main motivation of this project – to determine the most reliable method of predicting crashes in Louisiana for statewide implementation. Based on what the HSM says, it is expected that the state-specific SPFs would produce more accurate crash prediction results. Similar strategies in North Carolina, Florida, Utah, Kansas, Alabama, and Virginia have been evaluated to better predict the outcome of the Louisiana calibration effort.

The North Carolina team suggested taking the future application of the SPF into consideration when deciding which method to select, suggesting that there is no one “best” method for all cases. If the purpose of the SPFs is general network screening, developing a simple SPF based on AADT would be sufficient; however, if project-specific safety prediction is necessary, it would likely be more straightforward to calibrate the HSM SPFs [6].

After the calibration factors and local SPFs had been developed for the state of Florida, it was found that crash prediction was not improved overall by using the Florida-specific SPFs [5]. Utah found that both methods produced suitable results but that the local SPF required fewer data elements than the HSM SPF and would be simpler for use by local practitioners [2]. Alabama also found that the calibration factor and state-specific SPFs both produced reliable results but suggest that the calibration factor method is easier for practitioners to apply [7]. Kansas and Virginia found that the calibration factor applied to the HSM SPFs did not provide a reliable method for crash prediction and recommended the development of jurisdiction-specific SPFs [3,9].

Determining the best method of predicting average crash frequency depends on a variety of factors including the future application of the predictions as well as data availability within each state. Ideally, each state will develop calibration factors and state- or region-specific SPFs to determine which method provides the more reliable results.

OBJECTIVE

While there were various task items of work, the overriding objective of this project was to develop Louisiana state-specific calibration factors for the application of the HSM in Louisiana. This was accomplished by applying the methods described in the Part C predictive model Appendix A of the Highway Safety Manual using data collected for various roadway types in Louisiana. These segment types included:

- Rural Two-Lane-Two-Way Roads;
- Rural Four-Lane Divided (and Undivided Highways); and
- Urban and Suburban Arterials (including Two-Lane, Three-Lane with Center Two-Way Left-Turn-Lane (TWLTL), Four-Lane Divided and Undivided, and Five-Lane with Center TWLTL facilities).

Supporting the development of this primary objective were several other key tasks including the completion of a review of relevant literature to summarize the current state of HSM-application practice; the collection and analysis of Louisiana crash data as well as DOTD roadway traffic, design, and control data to support the creation of computational methods for factor calculation; followed by the development and adjustment of the factors.

SCOPE

The development of the HSM calibration factors for the various facility types in this study were based on a statewide database that included all parishes and city areas throughout Louisiana. As discussed previously, the segment types included:

- Rural Two-Lane-Two-Way Roads;
- Rural Four-Lane Divided (and Undivided Highways); and
- Urban and Suburban Arterials (including Two-Lane, Three-Lane with Center Two-Way Left-Turn-Lane (TWLTL), Four-Lane Divided and Undivided, and Five-Lane with Center TWLTL facilities);

for total of eight separate calibration factors. It is expected that these values will be applicable throughout the entire state of Louisiana.

The factors developed in this report did not include all possible geometric design and traffic control variables discussed in the HSM. This was because not all possible variables were included in the Louisiana DOTD statewide roadway database. It is expected that these limitations will be addressed in future efforts as more information becomes incorporated into the Louisiana roadway database.

SPFs are equations that estimate expected average crash frequency as a function of traffic volume and roadway characteristics (e.g., segment length, number of lanes, median type). Development of Louisiana-specific safety performance functions (SPFs) is not part of this scope of work. However, it is recognized that this work is being performed in parallel to this project by another research team.

METHODOLOGY

Although application of the HSM predictive method is new to Louisiana (as it is elsewhere) and some aspects of this project required developmental work, the primary objective of the study was based wholly on previously established methods documented in the HSM. The calibration procedure as outlined in Appendix A of Volume 2 and the predictive method as outlined in Chapters 10 – 12 of the HSM was followed to perform the calibration. All SPFs and CMFs found in the following sections can be found in the HSM. In this section, the process used to complete this calibration is discussed. This section also includes notable issues that arose during the calibration procedure and how they were resolved during the project process.

Calibration Procedure

The steps of the calibration process, as outlined in Appendix A, are given below:

Step 1 – Identify facility types for which the applicable Part C predictive model is to be calibrated.

Step 2 – Select sites for calibration of the predictive model for each facility type.

Step 3 – Obtain data for each facility type applicable to a specific calibration period.

Step 4 – Apply the applicable Part C predictive model to predict total crash frequency for each site during the calibration period as a whole.

Step 5 – Compute calibration factors for use in Part C predictive model.

The first step was completed before the project began – all eight segment facility types were to be calibrated. The third step was performed before the second step, in order for the sites to be selected from the statewide roadway database. Steps 2 through 5 are further discussed below.

Data Acquisition and Processing

This step of the project involved the acquisition and organization of roadway design and attribute data files and historical crash data from 2009 through 2011. All of these data were obtained from the Louisiana Department of Transportation and Development (DOTD). Using the DOTD roadway data file BM_STL_CONTROLS (last updated on March 14,

2013), analysis segments were selected for each facility type using the Highway Class identifier. A spreadsheet of key attributes was created for each of the eight facility types. An illustrative segment of this data file spreadsheet for Louisiana rural two-lane roads is shown in Figure 1.

	C	D	I	S	U	X	Y	AB	AF	AG	AH	AP	AZ
1	SECTION	SUBSECTION	SECTION_LEN	FED_AID_UF	HIGHWAY_CLASS	CENSUS_CATE	POP_GROUP	ADT	PAVEMENT_WIDTH	NUM_LANES	MEDIAN_TYPE	SHOULDER_WIDTH	CONTROL_SECTION
2	2	30	15.9499998	2	5	1	0	4619	0	0	0	0	829-26
3	2	60	5.8000002	2	5	1	0	4619	0	0	0	0	829-26
4	2	40	14.5500002	2	5	1	0	4619	0	0	0	0	829-26
5	2	20	1.04	2	5	2	1	4619	0	0	0	0	829-26
6	2	50	2.3	2	5	2	1	4619	0	0	0	0	829-26
7	1	10	0.4	1	1	1	0	6	18	2	1	8	848-06
8	3	30	0.81	1	1	1	0	28	22	2	1	3	824-06
9	3	20	2.8800001	1	1	1	0	28	22	2	1	3	824-06
10	3	10	4.8499999	1	1	1	0	28	20	2	1	5	824-06
11	3	10	4	1	1	1	0	36	18	2	1	3	822-01
12	4	50	3.01	1	1	1	0	42	21	2	1	4	408-02
13	1	10	0.2	1	1	1	0	42	20	2	1	4	821-26
14	1	20	5.9299998	1	1	1	0	51	20	2	1	4	181-02
15	1	15	3.95	1	1	1	0	51	20	2	1	3	181-01
16	1	10	4.0999999	1	1	1	0	51	20	2	1	3	181-01
17	3	70	1.36	1	1	1	0	58	24	2	1	9	042-07
18	3	60	2.6800001	1	1	1	0	58	20	2	1	3	042-07
19	3	50	0.57	1	1	1	0	58	20	2	1	4	042-07
20	1	10	1.88	1	1	1	0	58	20	2	1	3	813-06
21	1	30	0.03	1	1	1	0	58	24	2	1	9	812-07
22	1	10	1.41	1	1	1	0	58	20	2	1	6	812-07
23	1	80	0.07	1	1	1	0	71	22	2	1	13	854-09
24	1	70	0.7	1	1	1	0	71	20	2	1	2	854-09
25	1	60	0.05	1	1	2	1	71	20	2	1	2	854-09

Figure 1
Louisiana rural two-lane road data

In Figure 1, the way in which the Louisiana DOTD road data file was organized as well as how several of the key data variables required for the calculation of the calibration factors, such as average daily traffic (ADT); number of lanes; lane and shoulder widths; and so on, can be seen. Using this data, disaggregated by facility type, the spreadsheets were sorted by their average annual daily traffic (AADT). Segments whose AADT values were not within the range specified by the HSM were removed from the dataset. The HSM Part C SPFs are applicable for the following values of AADT:

- Rural Two-Lane: 0 to 17,800 vehicles per day
- Rural Four-Lane Divided: 0 to 89,300 vehicles per day
- Rural Four-Lane Undivided: 0 to 33,200 vehicles per day
- Urban Two-Lane: 0 to 32,600 vehicles per day
- Urban Three-Lane with TWLTL: 0 to 32,900 vehicles per day

- Urban Four-Lane Divided: 0 to 66,000 vehicles per day
- Urban Four-Lane Undivided: 0 to 40,100 vehicles per day
- Urban Five-Lane with TWLTL: 0 to 53,800 vehicles per day

All rural two-lane divided, rural five-lane with TWLTL, urban two-lane divided, and urban six- and eight-lane segments from the roadway data file had to be removed from the calibration set because the SPFs did not apply to segments of this type. The Census Category, Federal Aid Urban Area, and Population Group identifiers were used to determine whether a segment was located in a rural or urban area. Because these attributes did not always correspond with one another, when two of the three categories classified a segment as “rural,” the segment was moved to the rural spreadsheet, and likewise for urban segments.

Crash Data

Once all of the segments were classified by facility type, the next step was to use the 2009 - 2011 crash data to determine how many crashes occurred on each of the segments during the study period. Microsoft Excel Macros were written to link the segments in the roadway data file with the corresponding segments in the crash file based on the control section and logmile to/from identifiers. Three separate Excel files were required for the linking of the crash counts and road information. The first file (CRASHES) contained the list of all the crashes that occurred in Louisiana from 2009 through 2011 with relevant information associated with the crashes (e.g. control section mile, logmile, latitude, longitude, etc.). The second (CURVES) and third (INTERSECTIONS) files contained the list of all curves and intersections along state routes, including the control section and logmile to allow the files to be merged with the crash data.

Before performing the crash count of all the road types, intersection-related crashes were removed from the CRASHES file because this calibration focused on segment-related crashes. While the crashes in the crash database were coded as “intersection” or “non-intersection,” this was entered by the police officer who recorded the crash report. Because the officer’s definition of intersection crashes only included crashes occurring within the boundaries of the intersection, many crashes caused by or associated with the intersection were inadvertently excluded from this group. To account for this, intersection crashes were removed in three different ways: those that occurred within 50, or 150, or 250 feet from the intersection, respectively. In addition, and only for the rural two-lane road type, the crashes that occurred within a curve were also removed from the CRASHES file before running the corresponding crash count to eliminate the need for additional data collection for this facility

type. The curves were also removed from the segment length for the rural two lane segments; however, the distance for intersection-related crashes (50 ft., 150 ft., or 250 ft.) was not removed from the segment length. Excel Macros were used to eliminate the crashes related to intersections and/or within a curve comparing the control section and the logmile from the CRASHES file to the control section and the logmile-from and logmile-to of the INTERSECTIONS and/or the CURVES files as shown in Figure 2 and Figure 3.

Three different crash assessments were performed for every road type: one without the crashes that occurred within 50 ft. from the intersection, one without those within 150 ft., and one without those within 250 ft. For rural two-lane, however, the crashes that occurred within a curve (and the curve length) were also removed for all of the three crash counts in addition to those that occurred within the intersection influence area. It should be noted that crash reports were not reviewed for the exact cause and location of the crashes. The coordinates of the crashes as entered into the Louisiana database were simply compared to the locations of intersections to determine whether or not the crashes were “intersection-related” due to the time-consuming nature of reviewing each crash report. To count the total number of crashes that occurred within a road type, the control section and the logmile of the CRASHES file were compared to the control section and the logmile-from and logmile-to of the road type file and added to the number. Figure 4 shows a sample segment of the Excel Macro used to count the crashes for a particular road type.


```

Sub Intersections250ft()
    Dim i As Long
    Dim j As Long
    Dim ControlSection As String
    Dim LogMile As Double
    Dim IntersectionBook As Excel.Workbook
    Dim FileBook As Excel.Workbook

    Set FileBook = ActiveWorkbook
    Set IntersectionBook = Workbooks.Open("INTERSECTIONS.xlsx")

    i = 2
    j = 2

    Do Until 53698 = i - 1

        ControlSection = FileBook.Sheets("CRASHES").Cells(i, 4)
        LogMile = FileBook.Sheets("CRASHES").Cells(i, 5).Value
        Do Until 44002 = j - 1
            If IntersectionBook.Sheets("INT").Cells(j, 12) = ControlSection Then
                If LogMile >= IntersectionBook.Sheets("INT").Cells(j, 46) Then
                    If LogMile <= IntersectionBook.Sheets("INT").Cells(j, 47) Then
                        FileBook.Sheets("CRASHES").Cells(i, 23).Value = 1
                    End If
                End If
            End If
            j = j + 1
        Loop
        j = 2
        Do Until 4099 = j - 1
            If IntersectionBook.Sheets("INT2").Cells(j, 23) = ControlSection Then
                If LogMile >= IntersectionBook.Sheets("INT2").Cells(j, 46) Then
                    If LogMile <= IntersectionBook.Sheets("INT2").Cells(j, 47) Then
                        FileBook.Sheets("CRASHES").Cells(i, 23).Value = 1
                    End If
                End If
            End If
            j = j + 1
        Loop
        j = 2
        i = i + 1
    Loop

End Sub

```

Figure 2
Excel macro used to remove the crashes occurring within 250 ft. of an intersection

```

Sub CrashOnCurve()

    Dim i As Long
    Dim j As Long
    Dim ControlSection As String
    Dim LogMile As Long
    Dim RangeFrom As Long
    Dim RangeTo As Long
    Dim CrashCurveTotal As Long
    Dim CrashBook As Excel.Workbook
    Dim CurveBook As Excel.Workbook

    Set CrashBook = ActiveWorkbook
    Set CurveBook = Workbooks.Open("C:\Users\jrodr57\Desktop\CRASH OUT\All_Curves_Statewide_ARC.xlsx")

    i = 2
    j = 2

    Do Until 53698 = i - 1

        ControlSection = CrashBook.Sheets("CRASHES").Cells(i, 4)
        LogMile = CrashBook.Sheets("CRASHES").Cells(i, 5)

        Do Until 67111 = j - 1
            If CurveBook.Sheets("CURVES").Cells(j, 5) = ControlSection Then
                RangeFrom = CurveBook.Sheets("CURVES").Cells(j, 35).Value
                RangeTo = CurveBook.Sheets("CURVES").Cells(j, 36).Value
                If LogMile >= RangeFrom Then
                    If LogMile < RangeTo Then
                        CrashCurveTotal = CrashCurveTotal + 1
                        CrashBook.Sheets("CRASHES").Cells(i, 14) = "YES"
                    End If
                End If
            End If
            j = j + 1
        Loop
        j = 2

        CrashBook.Sheets("CRASHES").Cells(2, 17) = CrashCurveTotal
        If CrashBook.Sheets("CRASHES").Cells(i, 14) = "" Then
            CrashBook.Sheets("CRASHES").Cells(i, 14) = "NO"
        End If
        i = i + 1

    Loop
End Sub

```

Figure 3

Excel macro used to remove the crashes occurring within a curve for rural two-lane roads

```

Sub CrashCount150()

    Dim i As Long
    Dim j As Long
    Dim ControlSectionFile As String
    Dim RangeFrom As Double
    Dim RangeTo As Double
    Dim CrashTotal As Long
    Dim CrashBook As Excel.Workbook
    Dim FileBook As Excel.Workbook

    Set FileBook = ActiveWorkbook
    Set CrashBook = Workbooks.Open("CRASH_DATA_FOR_RURAL2LANE_150FT.xlsx")

    i = 2
    j = 2

    Do Until 67111 = i - 1

        ControlSectionFile = FileBook.Sheets("RURAL_TWO_LANE").Cells(i, 52)
        RangeFrom = FileBook.Sheets("RURAL_TWO_LANE").Cells(i, 53).Value
        RangeTo = FileBook.Sheets("RURAL_TWO_LANE").Cells(i, 54).Value

        Do Until 67111 = j - 1
            If CrashBook.Sheets("CRASHES").Cells(j, 4) = ControlSectionFile Then
                If CrashBook.Sheets("CRASHES").Cells(j, 5) >= RangeFrom Then
                    If CrashBook.Sheets("CRASHES").Cells(j, 5) <= RangeTo Then
                        CrashTotal = CrashTotal + 1
                    End If
                End If
            End If
            j = j + 1
        Loop

        FileBook.Sheets("RURAL_TWO_LANE").Cells(i, 85) = CrashTotal
        i = i + 1
        CrashTotal = 0

    Loop
End Sub

```

Figure 4

Excel macro used to count crashes for rural two-lane without crashes occurred on curves or within intersection radius of 150 ft.

Data Compilation and Computation

Despite its complexity, the highly systematic nature of the CMF computational process lent itself to spreadsheet-oriented calculation. To this end, project-specific macro routines were also written in Microsoft Excel to expedite the calibration procedure. These macros can be found in the Appendix of this report. Base SPFs were calculated for every segment within each spreadsheet using the equations found in Chapters 10 – 12 of the HSM. SPFs used in this process can also be found in the following section. Initially, these were calculated using only the data available in the DOTD roadway database. In later iterations, the missing data elements were collected using Google Earth only for the randomly selected segments due to the time-consuming nature of collecting data segment-by-segment. To collect the additional

data, the first step was to use the DOTD Latitude/Longitude conversion page to convert the control section and logmile to/from to latitude and longitude. During the data collection process, some segments were removed from the selection set, in which case new segments were randomly selected to replace them. These segments were removed due to coding errors (number of lanes or divided/undivided) or because they no longer existed (a bridge that had been removed).

SPFs and CMFs

Rural Two-Lane Segments

The SPF for predicted average crash frequency for rural two-lane road segments is

$$N_{\text{spf rs}} = \text{AADT} * L * 365 * 10^{-6} * e^{(-0.312)} \quad (2)$$

where,

$N_{\text{spf rs}}$ = predicted total average crash frequency for roadway segment base conditions,

AADT = average annual daily traffic volume (vehicles per day), and

L = length of roadway segment (miles).

This equation was used to calculate the predicted average crash frequency under base conditions. Initially, only the rural two-lane segment CMFs for lane width and shoulder width were applied, and base conditions were assumed for the remaining CMFs because of insufficient data. These CMFs included horizontal curves, grades, driveway density, shoulder type, centerline rumble strips, passing lanes, two-way left-turn lanes, roadside design, lighting, and automated speed enforcement. In the final iteration, rural two-lane curves were removed from the segments, leaving only tangent sections, eliminating the need for additional curve data. Data for the remaining CMFs was then gathered using Google Earth for each of the selected segments.

For the rural two-lane lane width and shoulder width CMFs, the default value for “proportion of total crashes constituted by related crashes” (P_{RA}) was used. This value indicated that run-off-the-road, head-on, and sideswipe crashes typically represent 57.4 percent of total crashes for rural two-lane segments. Local data can be used to update these numbers in the future to better reflect Louisiana conditions.

Rural Multilane Highways

The SPF for predicted average crash frequency for rural multilane undivided segments is:

$$N_{\text{spf ru}} = e^{(a + b * \ln(\text{AADT}) + \ln(L))} \quad (3)$$

where,

$N_{spf\ ru}$ = predicted total average crash frequency for roadway segment base conditions,
AADT = average annual daily traffic volume (vehicles per day) on roadway segment,
L = length of roadway segment (miles), and
a,b = regression coefficients (-9.653 and 1.176 respectively for total crashes).

The SPF for predicted average crash frequency for rural multilane divided segments is:

$$N_{spf\ rd} = e^{(a + b * \ln(AADT) + \ln(L))} \quad (4)$$

where,

$N_{spf\ rd}$ = predicted total average crash frequency for roadway segment base conditions,
AADT = average annual daily traffic volume (vehicles per day) on roadway segment,
L = length of roadway segment (miles), and
a,b = regression coefficients (-9.025 and 1.049 respectively for total crashes).

These SPFs were used to calculate the predicted average crash frequency under base conditions. The rural multilane undivided segment CMFs for lane width and shoulder width were then applied. Initially, base conditions were assumed for the CMFs for shoulder type, sideslopes, lighting, and automated speed enforcement. In the final iteration, data for the shoulder type and lighting CMFs was gathered in Google Earth. The sideslopes were roughly approximated based on reviews of the road segments in Google Earth, and no automated speed enforcement was assumed. For the rural multilane divided segments, the lane width, right shoulder width, and median width CMFs were initially applied, but the lighting and automated speed enforcement CMFs could not be calculated due to insufficient data. Lighting data was gathered using Google Earth, and no automated speed enforcement was assumed in all cases.

For the rural multilane lane width and shoulder width CMFs, the default values for “proportion of total crashes constituted by related crashes” (P_{RA}) were used. These values indicate that run-off-the-road, head-on, and sideswipe crashes typically represent 27 percent and 50 percent of total crashes for rural multilane undivided and divided segments, respectively. Local data can be used to update these numbers in the future to better reflect Louisiana-specific conditions.

Urban and Suburban Arterials

The predictive models for urban and suburban roadway segments were as follows:

$$N_{\text{predicted rs}} = C_r * (N_{\text{br}} + N_{\text{pedr}} + N_{\text{biker}}) \quad (5)$$

$$N_{\text{br}} = N_{\text{spf rs}} * (CMF_{1r} * CMF_{2r} * \dots * CMF_n) \quad (6)$$

$$N_{\text{spf rs}} = N_{\text{brmv}} + N_{\text{brsv}} + N_{\text{brdwy}} \quad (7)$$

$$N_{\text{brmv}} = \exp(a + b * \ln(\text{AADT}) + \ln(L)) \quad (8)$$

where,

$N_{\text{predicted rs}}$ = predicted average crash frequency of an individual roadway segment,

C_r = calibration factor for roadway segments developed for use for a particular geographical area,

N_{br} = predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions),

N_{pedr} = predicted average crash frequency of vehicle-pedestrian collisions for an individual roadway segment,

N_{biker} = predicted average crash frequency of vehicle-bicycle collisions for an individual roadway segment,

$N_{\text{spf rs}}$ = predicted total average crash frequency for roadway segment base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions),

$CMF_{1r} \dots CMF_{nr}$ = crash modification factors for roadway segments,

N_{brmv} = predicted average crash frequency of multiple-vehicle non-driveway collisions for base conditions,

N_{brsv} = predicted average crash frequency of single-vehicle crashes for base conditions,

N_{brdwy} = predicted average crash frequency of multiple-vehicle driveway collisions for base conditions,

AADT = average annual daily traffic volume (vehicles per day) on roadway segment,

L = length of roadway segment (miles), and

a,b = regression coefficients, which for total crashes are as follows

– For multiple vehicle non-driveway collisions

- 2U: -15.22, 1.68
- 3T: -12.40, 1.41
- 4U: -11.63, 1.33
- 4D: -12.34, 1.36
- 5T: -9.70, 1.17

– For single vehicle collisions

- 2U: -5.47, 0.56
- 3T: -5.74, 0.54
- 4U: -7.99, 0.81
- 4D: -5.05, 0.47
- 5T: -4.82, 0.54

Initially, only two of the five urban/suburban SPFs (multiple-vehicle non-driveway collisions and single-vehicle crashes) were estimated, and the remaining three (multiple-vehicle driveway-related collisions, vehicle-pedestrian collisions, and vehicle-bicycle collisions) were excluded due to lack of data on number of driveways by land-use type and posted speed data. In the initial calibration effort, only the median width CMF was applied, and base conditions were assumed for the remaining CMFs because of insufficient data. These CMFs include on-street parking, roadside fixed objects, lighting, and automated speed enforcement. The missing data was then collected for the final iteration on the selected segments using Google Earth. The driveways were counted individually by type, and information was gathered on posted speed, on-street parking, roadside fixed objects, and lighting, and it was assumed that there was no automated speed enforcement.

The urban and suburban SPFs can be calculated for total crashes, fatal-and-injury crashes, and property-damage-only crashes using the HSM. In this project, only total crashes were estimated.

Calculating Calibration Factors

Once the SPFs and CMFs were estimated, they were multiplied together to obtain the predicted crash frequency along each segment. The predicted crashes and the observed crashes along the selected segments were added, and calibration factors (C) were then calculated for each facility type by dividing the total observed crashes by the total predicted crashes for that particular roadway type.

In the first iteration of calibration factors, fifty segments were randomly selected without removing the intersection crashes and without collecting additional data. The random selection was done within the Excel spreadsheets using a random number generator. In the second iteration, no additional data was collected, but crashes occurring within 250 ft. of the center of the intersection were removed, and curve crashes were removed for rural two-lane roads. The length of the curves, but not the distance from the center of the intersections, was removed from the segment length. The removal of intersection crashes required the selection of a greater number of segments for some facility types to reach the 100 annual crash

minimum. A third iteration of calibration factors was calculated using the same methods of the second iteration, but it included every segment in the database in hopes of lessening the potential skewing of the results due to outliers. In the fourth and final iteration, segments were randomly selected using a random number generator, missing data elements were collected using Google Earth, and intersection crashes were removed in three different ways – 50 ft. from the center of the intersection, 150 ft., and 250 ft.

It should be noted that all segments were used in calculating the urban three-lane calibration factor in all iterations because only 32 segments fell into this facility type. The final results from these processes can be found in the next section.

DISCUSSION OF RESULTS

In the first iteration, an initial set of preliminary calibration factors were computed for eight facility types – rural two-lane roads, rural multilane divided highways, rural multilane undivided highways, urban two-lane roads, urban three-lane roads with center TWLTL, urban four-lane divided highways, urban four-lane undivided highways, and urban five-lane highways with center TWLTL. This first iteration was calculated without “additional” data collected from sources outside of the DOTD road database and with intersection-related crashes, identified as such within the Louisiana traffic crash data file, removed from the analysis pool. While this was known to be a less than desirable condition, it was completed to establish a “base-line” condition of what could be quickly developed based on the available data. However, given that there were so many missing data elements from this initial set of calibration factors, it was recognized that it does not reflect true conditions.

The first iteration (with no additional data) was used as the basis for the second and third iterations. In these trials, however, the definition of intersection-related crashes was modified for comparative purposes. Rather than identifying an intersection-related crash strictly based on its designation on the crash report form, crash locations were located based on the latitude and longitude coordinates included on the form. Based on this, any crash occurring within 250 ft. of the center point of an intersection were deemed to be intersection-related and they were removed from the segment. Based on additional information, crashes occurring on curves of two-lane rural roads were also able to be identified and those were removed from the samples as well. For the second iteration, segments were selected based on the standard HSM procedure which suggests a process of random selected until the 100 crash minimum was reached. Then, for the third iteration, all segments were included in the Louisiana data base with the expectation that the effect of “outliers” (exceptionally narrow lanes, shoulders, etc.) would be reduced. Once again, however, the calibration factors that resulted from the second and third iterations were assumed to be unreliable because of the numerous missing data elements.

In the fourth and final iteration, a considerable amount of additional data elements were included in the computational process. In it, segments were randomly selected as before, but then reviewed individually, segment-by-segment, using Google Earth to collect key characteristics (driveway type and density, lighting, embankment slope, etc.) that were not available in the DOTD roadway database.

The results from all of these iterations, as well as a sub-comparison that included varying the definition of an intersection-related crash, by removing crashes within 50, 150, and 250 feet from center point, are shown in Table 1.

Table 1
Calibration factors by facility type

	1st Iteration ¹		2nd Iteration ²		3rd Iteration ³	
Facility Type	Calibration Factor	Number of Segments	Calibration Factor	Number of Segments	Calibration Factor	Number of Segments
Rural Two Lane	1.86	50	0.75	100	0.73	6,188
Rural Multilane Undivided	1.37	50	0.63	150	0.53	219
Rural Multilane Divided	2.36	50	1.10	50	1.21	521
Urban Two Lane	2.02	50	1.79	50	2.06	1,403
Urban Three Lane with TWLTL	2.85	32	0.26	32	0.26	32
Urban Four Lane Undivided	5.20	50	1.03	50	1.41	469
Urban Four Lane Divided	8.13	50	1.87	50	2.15	553
Urban Five Lane with TWLTL	0.51	50	0.04	226	0.03	226
	4th Iteration ⁴					
	50 ft. Removed		150 ft. Removed		250 ft. Removed	
Facility Type	Calibration Factor	Number of Segments	Calibration Factor	Number of Segments	Calibration Factor	Number of Segments
Rural Two Lane	1.13	99	0.97	99	0.86	99
Rural Multilane Undivided	0.91	80	0.62	80	0.47	80
Rural Multilane Divided	2.41	50	1.92	50	1.62	50
Urban Two Lane	2.74	30	1.91	30	1.39	30
Urban Three Lane with TWLTL	0.49	32	0.26	32	0.18	32
Urban Four Lane Undivided	3.20	49	1.59	49	0.91	49
Urban Four Lane Divided	3.89	49	2.54	49	1.92	49
Urban Five Lane with TWLTL	0.07	145	0.06	145	0.05	145

- (1) No additional data outside of DOTD database, no curve or “additional” intersection crashes removed
- (2) No additional data outside of DOTD database, curved segments removed from (rural two lane) random selection process, crashes from within 250 ft. of intersections removed
- (3) No additional data outside of DOTD database, curved segments removed from (rural two lane) random selection process, crashes from within 250 ft. of intersections removed, all segments included
- (4) Additional data collected, curves removed, crashes occurring within 50 ft., 150 ft., and 250 ft. removed from database

CONCLUSIONS

The goal of this project was to develop calibration factors for various roadway facility types in Louisiana as presented in Table 1. For comparative purposes and to demonstrate the effect of including or excluding various data elements and crash records, the factors were computed as a series of iterations. These iterations demonstrated the variability and, arguably, the accuracy of these factors when including data that was easily and quickly accessible in the DOTD roadway database and by excluding crashes that occurred within various distances away from intersections. The practical implications of this process and results are thought to be important because there is a clear trade-off between factor assumed accuracy and data coding effort. The inclusion of driveways into the computational process required hundreds of labor hours to include enough for the minimum sample size. However, the inclusion of this data for the effects of these changed the final results by 20 to 30 percent and in one case, more than 60 percent. Based on these findings and the practices recommended in the HSM, it is recommended that future users of these findings use the calibration factors of Iteration 4 that were developed by removing crashes that occurred within 150 feet of the center of the intersection.

The values for rural multilane undivided and divided highways, 0.62 and 1.92, are not identical, but reasonably similar to values (0.98 and 1.25, respectively) computed by researchers at the University of Louisiana Lafayette in a 2010 study [10]. This suggests some level of consistency in crashes on rural multilane highways since their data collection was completed over the four year span since 2007. These calibration factors also suggest that the road types with the most significant safety issues in Louisiana are rural multilane divided, urban two-lane, and urban four-lane divided, as these experience about 1.92, 1.91, and 2.54 times, respectively, the number of crashes predicted when using the uncalibrated HSM SPFs.

RECOMMENDATIONS

Based on the methods used here and the extensive systematic collection of additional detailed roadway elements from online aerial photographic data sources, these calibration factors (fourth iteration with crashes within 150 ft. removed) are regarded to represent the most accurate figures currently available in the state of Louisiana. Thus, it is recommended that they be approved for use in broadly assessing safety conditions in the state with the understanding of the assumptions and data availability limitations under which data was collected and processed.

Future Work

Although this project has been completed as specified in the project contract, there are a number of areas and issues that could be considered for further analysis and assessment to continue to improve and update these factors.

Among the concerns that arose during this project was the potential for use of miscoded intersection-related crashes. In the future, and preferably before these factors are applied, the calibration factors found in this report or the updated calibration factors should be computed by individually reviewing each crash report to verify whether the crash is intersection- or segment-related.

Another area of potential future work is the possibility of including more in depth statistical analyses, incorporating among other factors, standard deviation, over dispersion parameters, etc. There was also a suggestion to undertake further randomly selection of segments until the standard deviation was within an “acceptable” range of error. Currently, the calibration factors developed in this report are being used to predict 2012 crashes and will then be compared to the actual 2012 historic crash records. Once available, the results of this analysis will be made available to DOTD.

The HSM recommends that factors should be recalculated every three years to reflect changes in traffic and road conditions. In addition, it is recommended that the SPFs and calibration factors be periodically redeveloped or recalibrated to reflect future changes in vehicle technology and/or design and safety treatments, accordingly [1]. The SPFs may either be redeveloped in the future or a calibration factor can be calculated for each future year. While not part of this project, it is worth noting the importance of these updates for long term analysis in the state.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
HSM	Highway Safety Manual
FHWA	Federal Highway Administration
DOTD	Louisiana Department of Transportation and Development
ALDOT	Alabama Department of Transportation
FDOT	Florida Department of Transportation
KDOT	Kansas Department of Transportation
NCDOT	North Carolina Department of Transportation
ODOT	Oregon Department of Transportation
UDOT	Utah Department of Transportation
LTRC	Louisiana Transportation Research Center
SPF	Safety Performance Function
CMF	Crash Modification Factor
C	Calibration Factor
$N_{\text{predicted}}$	Predicted Average Crash Frequency
TWLTL	Two-Way Left-Turn-Lane
AADT	Average Annual Daily Traffic Volume (vehicles per day)
P_{RA}	Proportion of Total Crashes Constituted by Related Crashes
2U	Urban/Suburban Two-Lane Road
3T	Urban/Suburban Three-Lane Highway with TWLTL
4U	Urban/Suburban Four-Lane Undivided Highway
4D	Urban/Suburban Four-Lane Divided Highway
5T	Urban/Suburban Five-Lane Highway with TWLTL
L	Length of Roadway Segment (miles)
a,b	Regression Coefficients
C_r	Calibration Factor for Roadway Segments of a Specific Type Developed for use for a Particular Geographical Area
$N_{\text{spf ru}}$	Base Total Expected Average Crash Frequency for a Roadway Segment
$N_{\text{spf rs}}$	Predicted Total Average Crash Frequency for Roadway Segment Base Conditions
$N_{\text{spf rd}}$	Base Total Expected Average Crash Frequency for a Roadway Segment
$N_{\text{predicted rs}}$	Predicted Average Crash Frequency of an Individual Roadway Segment for the Selected Year
N_{br}	Predicted Average Crash Frequency of an Individual Roadway Segment (excluding vehicle-pedestrian and vehicle-bicycle collisions)

N_{pedr}	Predicted Average Crash Frequency of Vehicle-Pedestrian Collisions for an Individual Roadway Segment
N_{biker}	Predicted Average Crash Frequency of Vehicle-Bicycle Collisions for an Individual Roadway Segment
N_{brmv}	Predicted Average Crash Frequency of Multiple-Vehicle Non-Driveway Collisions for Base Conditions
N_{brsv}	Predicted Average Crash Frequency of Single-Vehicle Crashes for Base Conditions
N_{brdwy}	Predicted Average Crash Frequency of Multiple-Vehicle Driveway Collisions for Base Conditions

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APPENDIX

Rural Two-Lane Segments

The rural two-lane segment CMFs for lane width and shoulder width were calculated using the following Macros.

Lane Width Code

```
Select Case LaneWidth
  Case Is <= 9
    Select Case AADT
      Case Is < 400
        Cells(i, 68).Value = 1.05
      Case 400 To 2000
        Cells(i, 68).Value = 1.05 + 0.000281 * (AADT - 400)
      Case Is > 2000
        Cells(i, 68).Value = 1.5
    End Select
  Case 10
    Select Case AADT
      Case Is < 400
        Cells(i, 68).Value = 1.02
      Case 400 To 2000
        Cells(i, 68).Value = 1.02 + 0.000175 * (AADT - 400)
      Case Is > 2000
        Cells(i, 68).Value = 1.3
    End Select
  Case 11
    Select Case AADT
      Case Is < 400
        Cells(i, 68).Value = 1.01
      Case 400 To 2000
        Cells(i, 68).Value = 1.01 + 2.5e-05 * (AADT - 400)
      Case Is > 2000
        Cells(i, 68).Value = 1.05
    End Select
  Case Is >= 12
    Cells(i, 68).Value = 1
End Select
```

Shoulder Width Code

```
Select Case ShoulderWidth
  Case 0
```

```

Select Case AADT
  Case Is < 400
    Cells(i, 68).Value = 1.1
  Case 400 To 2000
    Cells(i, 68).Value = 1.1 + 0.00025 * (AADT - 400)
  Case Is > 2000
    Cells(i, 68).Value = 1.5
End Select
Case 1
  Select Case AADT
    Case Is < 400
      Cells(i, 68).Value = 1.085
    Case 400 To 2000
      Cells(i, 68).Value = 1.085 + 0.0001965 * (AADT -
400)
    Case Is > 2000
      Cells(i, 68).Value = 1.4
    End Select
  End Select
Case 2
  Select Case AADT
    Case Is < 400
      Cells(i, 68).Value = 1.07
    Case 400 To 2000
      Cells(i, 68).Value = 1.07 + 0.000143 * (AADT - 400)
    Case Is > 2000
      Cells(i, 68).Value = 1.3
    End Select
  End Select
Case 3
  Select Case AADT
    Case Is < 400
      Cells(i, 68).Value = 1.045
    Case 400 To 2000
      Cells(i, 68).Value = 1.045 + 0.000112125 * (AADT -
400)
    Case Is > 2000
      Cells(i, 68).Value = 1.225
    End Select
  End Select
Case 4
  Select Case AADT
    Case Is < 400
      Cells(i, 68).Value = 1.02
    Case 400 To 2000
      Cells(i, 68).Value = 1.02 + 0.00008125 * (AADT -
400)
    Case Is > 2000
      Cells(i, 68).Value = 1.15

```

```

End Select
Case 5
  Select Case AADT
    Case Is < 400
      Cells(i, 68).Value = 1.01
    Case 400 To 2000
      Cells(i, 68).Value = 1.01 + 0.000040625 * (AADT -
400)
    Case Is > 2000
      Cells(i, 68).Value = 1.075
  End Select
Case 6
  Cells(i, 68).Value = 1
Case 7
  Select Case AADT
    Case Is < 400
      Cells(i, 68).Value = 0.99
    Case 400 To 2000
      Cells(i, 68).Value = 0.99 + 0.000034375 * (AADT -
400)
    Case Is > 2000
      Cells(i, 68).Value = 0.935
  End Select
Case Is >= 8
  Select Case AADT
    Case Is < 400
      Cells(i, 68).Value = 0.98
    Case 400 To 2000
      Cells(i, 68).Value = 0.98 + 0.00006875 * (AADT -
400)
    Case Is > 2000
      Cells(i, 68).Value = 0.87
  End Select
End Select

```

Rural Multilane Highways

The rural multilane undivided segment CMFs for lane width and shoulder width were calculated using the following Macros.

Rural Multilane Undivided Lane Width Code

```

Select Case LaneWidth
  Case Is <= 9.25
    Select Case AADT

```

```

Case Is < 400
    Cells(i, 66).Value = (1.04 - 1) * 0.27 + 1
Case 400 To 2000
    Val = 1.04 + 0.000213 * (AADT - 400)
    Val = (Val - 1) * 0.27
    Cells(i, 66).Value = Val + 1
Case Is > 2000
    Cells(i, 66).Value = (1.38 - 1) * 0.27 + 1
End Select
Case 9.26 To 9.75
    Select Case AADT
        Case Is < 400
            Cells(i, 66).Value = (1.03 - 1) * 0.27 + 1
        Case 400 To 2000
            Val = 1.03 + 0.000172 * (AADT - 400)
            Val = (Val - 1) * 0.27
            Cells(i, 66).Value = Val + 1
        Case Is > 2000
            Cells(i, 66).Value = (1.305 - 1) * 0.27 + 1
    End Select
Case 9.76 To 10.25
    Select Case AADT
        Case Is < 400
            Cells(i, 66).Value = (1.02 - 1) * 0.27 + 1
        Case 400 To 2000
            Val = 1.02 + 0.00031 * (AADT - 400)
            Val = (Val - 1) * 0.27
            Cells(i, 66).Value = Val + 1
        Case Is > 2000
            Cells(i, 66).Value = (1.23 - 1) * 0.27 + 1
    End Select
Case 10.26 To 10.75
    Select Case AADT
        Case Is < 400
            Cells(i, 66).Value = (1.015 - 1) * 0.27 + 1
        Case 400 To 2000
            Val = 1.015 + 0.0000749 * (AADT - 400)
            Val = (Val - 1) * 0.27
            Cells(i, 66).Value = Val + 1
        Case Is > 2000
            Cells(i, 66).Value = (1.135 - 1) * 0.27 + 1
    End Select
Case 10.76 To 11.25
    Select Case AADT
        Case Is < 400
            Cells(i, 66).Value = (1.01 - 1) * 0.27 + 1

```

```

Case 400 To 2000
    Val = 1.01 + 0.0000188 * (AADT - 400)
    Val = (Val - 1) * 0.27
    Cells(i, 66).Value = Val + 1
Case Is > 2000
    Cells(i, 66).Value = (1.04 - 1) * 0.27 + 1
End Select
Case Is >= 11.26
    Cells(i, 66).Value = 1
End Select

```

Rural Multilane Undivided Shoulder Width Code

```

Select Case ShoulderWidth
Case 0
    Select Case AADT
    Case Is < 400
        Cells(i, 67).Value = (1.1 - 1) * 0.27 + 1
    Case 400 To 2000
        Val = 1.01 + 0.00025 * (AADT - 400)
        Val = (Val - 1) * 0.27
        Cells(i, 67).Value = Val + 1
    Case Is > 2000
        Cells(i, 67).Value = (1.5 - 1) * 0.27 + 1
    End Select
Case 1
    Select Case AADT
    Case Is < 400
        Cells(i, 67).Value = (1.085 - 1) * 0.27 + 1
    Case 400 To 2000
        Val = 1.085 + 0.000197 * (AADT - 400)
        Val = (Val - 1) * 0.27
        Cells(i, 67).Value = Val + 1
    Case Is > 2000
        Cells(i, 67).Value = (1.4 - 1) * 0.27 + 1
    End Select
Case 2
    Select Case AADT
    Case Is < 400
        Cells(i, 67).Value = (1.07 - 1) * 0.27 + 1
    Case 400 To 2000
        Val = 1.07 + 0.000143 * (AADT - 400)
        Val = (Val - 1) * 0.27
        Cells(i, 67).Value = Val + 1
    Case Is > 2000
        Cells(i, 67).Value = (1.3 - 1) * 0.27 + 1
    End Select

```

```

End Select
Case 3
  Select Case AADT
    Case Is < 400
      Cells(i, 67).Value = (1.045 - 1) * 0.27 + 1
    Case 400 To 2000
      Val = 1.045 + 0.000112 * (AADT - 400)
      Val = (Val - 1) * 0.27
      Cells(i, 67).Value = Val + 1
    Case Is > 2000
      Cells(i, 67).Value = (1.22 - 1) * 0.27 + 1
  End Select
Case 4
  Select Case AADT
    Case Is < 400
      Cells(i, 67).Value = (1.02 - 1) * 0.27 + 1
    Case 400 To 2000
      Val = 1.02 + 0.00008125 * (AADT - 400)
      Val = (Val - 1) * 0.27
      Cells(i, 67).Value = Val + 1
    Case Is > 2000
      Cells(i, 67).Value = (1.15 - 1) * 0.27 + 1
  End Select
Case 5, 6, 7
  Cells(i, 67).Value = 1
Case Is >= 8
  Select Case AADT
    Case Is < 400
      Cells(i, 67).Value = (0.98 - 1) * 0.27 + 1
    Case 400 To 2000
      Val = 0.98 - 0.00006875 * (AADT - 400)
      Val = (Val - 1) * 0.27
      Cells(i, 67).Value = Val + 1
    Case Is > 2000
      Cells(i, 67).Value = (0.87 - 1) * 0.27 + 1
  End Select
End Select

```

For the rural multilane divided segments, the lane width, right shoulder width, and median width CMFs were calculated using the following Macros.

Rural Multilane Divided Lane Width Code

```

Select Case LaneWidth
  Case Is <= 9.5
    Select Case AADT

```



```

    Case Is < 400
        Cells(i, 68).Value = (1.03 - 1) * 0.5 + 1
    Case 400 To 2000
        Val = 1.03 + 0.000138 * (AADT - 400)
        Val = (Val - 1) * 0.5
        Cells(i, 68).Value = Val + 1
    Case Is > 2000
        Cells(i, 68).Value = (1.25 - 1) * 0.5 + 1
End Select
Case 9.6 To 10.5
    Select Case AADT
        Case Is < 400
            Cells(i, 68).Value = (1.01 - 1) * 0.5 + 1
        Case 400 To 2000
            Val = 1.01 + 8.75e-05 * (AADT - 400)
            Val = (Val - 1) * 0.5
            Cells(i, 68).Value = Val + 1
        Case Is > 2000
            Cells(i, 68).Value = (1.15 - 1) * 0.5 + 1
    End Select
Case 10.6 To 11.5
    Select Case AADT
        Case Is < 400
            Cells(i, 68).Value = (1.01 - 1) * 0.5 + 1
        Case 400 To 2000
            Val = 1.01 + 1.25e-05 * (AADT - 400)
            Val = (Val - 1) * 0.5
        Case Is > 2000
            Cells(i, 68).Value = (1.03 - 1) * 0.5 + 1
    End Select
Case Is >= 11.6
    Cells(i, 68).Value = 1
End Select

```

Rural Multilane Divided Shoulder Width Code

```

Select Case ShoulderWidth
    Case 0
        Cells(i, 70).Value = 1.18
    Case 1
        Cells(i, 70).Value = 1.16
    Case 2
        Cells(i, 70).Value = 1.13
    Case 3
        Cells(i, 70).Value = 1.11
    Case 4

```

```

        Cells(i, 70).Value = 1.09
Case 5
        Cells(i, 70).Value = 1.07
Case 6
        Cells(i, 70).Value = 1.04
Case 7
        Cells(i, 70).Value = 1.02
Case Is >= 8
        Cells(i, 70).Value = 1
End Select

```

Rural Multilane Divided Median Width Code

```

Select Case MedianWidth
Case 0 To 14
        Cells(i, 69).Value = 1.04
Case 15 To 24
        Cells(i, 69).Value = 1.02
Case 25 To 34
        Cells(i, 69).Value = 1
Case 35 To 44
        Cells(i, 69).Value = 0.99
Case 45 To 54
        Cells(i, 69).Value = 0.97
Case 55 To 64
        Cells(i, 69).Value = 0.96
Case 65 To 74
        Cells(i, 69).Value = 0.96
Case 75 To 84
        Cells(i, 69).Value = 0.95
Case 85 To 94
        Cells(i, 69).Value = 0.94
Case Is >= 95
        Cells(i, 69).Value = 0.94
End Select

```

Urban and Suburban Arterials

The urban/suburban segment CMF for median width was calculated using the follow Macro.

```

Select Case MedianWidth
Case 0 To 11
        Cells(i, 70).Value = 1.01
Case 12 To 18
        Cells(i, 70).Value = 1
Case 19 To 24

```

```
    Cells(i, 70).Value = 0.99
Case 25 To 34
    Cells(i, 70).Value = 0.98
Case 35 To 44
    Cells(i, 70).Value = 0.97
Case 45 To 54
    Cells(i, 70).Value = 0.96
Case 55 To 64
    Cells(i, 70).Value = 0.95
Case 65 To 74
    Cells(i, 70).Value = 0.94
Case 75 To 84
    Cells(i, 70).Value = 0.93
Case 85 To 94
    Cells(i, 70).Value = 0.93
Case Is >= 95
    Cells(i, 70).Value = 0.92
End Select
```